P516811.PDF [Page: 3 of 39]

FORCED AIR WARMING SYSTEM

PROTOTYPE III

FINAL REPORT

FORCED AIR WARMING SYSTEM – PROTOTYPE III

FINAL REPORT

By

Jason Leggatt

Mustang Survival Corporation
Technical Product Development
3810 Jacombs Road
Richmond, British Columbia
Canada V6V 1Y6

PWGSC CONTRACT NO. W7711-8-7479/01-SRV

ORDER NO. 7479-5

On behalf of
DEPARTMENT OF NATIONAL DEFENCE

As represented by
Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West
North York, Ontario
Canada M3M 3B9

DCIEM Scientific Authority
Michel Ducharme, Ph.D.
Ph. (416) 635-2186

Prepared October 15, 2001

©HER MAJESTY THE QUEEN IN RIGHT OF CANADA (2001) as represented by the Minister of National Defence

104-06277/

P516811.PDF [Page: 5 of 39]

EXECUTIVE SUMMARY

This report details the design and development of a Forced Air Warming (FAW) system for the Defence and Civil Institute of Environmental Medicine (DCIEM). Mustang Survival Corporation partnered with DCIEM in the development of two previous versions of FAW systems. Thus the present version has been appropriately named the FAW III.

Previous versions of the FAW concept successfully demonstrated that such a system, if deployed in the field, would have the capability of providing a 30% increase in re-warming efficiency compared to warming bags currently used during Search and Rescue (SAR) operations. Current field treatment systems for hypothermia use a combination of active and passive warming. The primary mode of heat transfer in these systems is conduction; the bag is actively heated. Passive insulation is used to mitigate against heat loss to the environment. The premise of the FAW system is to utilize a higher form of heat transfer, convection, for immediate treatment of subjects suffering from hypothermia. This is achieved by creating a heated microenvironment around the subject's body by blowing heated air through air distribution manifolds. However, several limitations for the field use of the previous two prototypes were identified and a third iteration of the FAW was initiated. The purpose of the present FAW is to lay the groundwork for a final design that will ultimately lead to a commercially available system.

The FAW III system serves the following two primary functions in re-warming a subject.

- Passive insulation and passive re-warming of the subject's legs and arms.
- Active forced air warming of the subject's torso and back of the head by means of a heated microenvironment.

The current version of the FAW was designed to be integrated with a Stokes rescue litter. A vinyl coated foam blanket is used to insulate the stretcher bottom and was designed to mate with the litter frame and the body supporting suspension system. A custom suspension system supports the body out of the bottom of the litter. The upper body portion was constructed from nylon webbing in a box-shaped pattern so that the back of the subject will be largely exposed, approximately 50%. The lower body and legs are supported on a solid canvas bed that rests on top of the electronics box component. A body harness design is also incorporated into the litter system. These components are intended to be permanently installed but can be easily removed for laundering. The lower air distribution manifold connects to the foam insulation blanket and may either be left in the litter or stored separately.

Additional components of the FAW system are stored in a carrying bag. Passive insulation components for the arms and the legs are installed on the subject and tightened to dam the passage of air from the heated chamber to the extremities.

P516811.PDF [Page: 6 of 39]

Finally, a dome is installed over the torso section of the body and mates with the suspension and foam insulation components. This dome supports the upper air distribution manifold over the torso of the subject's body. A hood cover, integrated into the torso cover design, mates around the subject's head and the foam insulation blanket to seal the heated microenvironment.

The electronic components of the system, including the controls system, heaters, blower and displays are to be supplied and installed by DCIEM. Accommodation for integration of the electronics to the FAW was considered throughout the design stage. Complementary treatments and additional features will be integrated into the FAW design during and following testing and evaluation of the prototype at DCIEM.

P516811.PDF [Page: 7 of 39]

TABLE OF CONTENTS

EXECUTIVE SUMMARY I

LIST OF FIGURES IV

LIST OF TABLES V

1. INTRODUCTION 1

2. FAW III GENERAL DESCRIPTION 2

3. COMPONENT DESIGNS 5

3.1. Lower Insulation Blanket (LIB) 5
3.2. Suspension System 6
3.3. Subject Harness 8
3.4. Passive Insulation for the Limbs 9
3.4.1. Arm Insulation 9
3.4.2. Leg Insulation 10
3.5. Torso Cover 11
3.6. Hood 14
3.7. Air Distribution 15
3.7.1. Lower Manifold 15
3.7.2. Upper Manifold 17
3.8. Carrying Bag 17
3.9. Integration of Complementary Treatments 18

4. CONSTRUCTION 19

4.1. Manufacturing Techniques 19
4.2. List of Materials 20

5. ASSEMBLY INSTRUCTIONS 23

6. CONCLUSION 24

7. RECOMMENDATIONS 25

APPENDIX: SUPPLEMENTAL PHOTOGRAPHS 26

P516811.PDF [Page: 8 of 39]

LIST OF FIGURES

Figure 2-1a	Standard Stokes Rescue Litter	2
Figure 2-1b	Final Assembly or the FAW III Prototype	2
Figure 2-2	Permanently Installed Components in the Stretcher System	3
Figure 3.1-1a	Sketch – LIB Bottom Side	5
Figure 3.1-1b	Sketch – LIB Top Side	6
Figure 3.2-1	Fixed Link Attachment System	7
Figure 3.2-2	Final FAW III Prototype Suspension System	8
Figure 3.3-1	Subject Restraint System – Upper	8
Figure 3.4.1-1	Arm Insulation Components	9
Figure 3.4.2-1	FAW III Leg Insulation Component	10
Figure 3.5-1	Inflatable Mattress Torso Cover Gluing Lay-up	12
Figure 3.5-2	Final Prototype Torso Cover Component	13
Figure 3.5-3	Torso Cover in the Packed Configuration	14
Figure 3.6-1	Hood Component	14
Figure 3.7.1-1	Lower Air Distribution Manifold Sketch	16
Figure 3.7.2-1	Upper Air Distribution Manifold Sketch	17
Figure A-1	FAW Final Assembly – Top View	26
Figure A-2	Installation of the Subject	26
Figure A-3	Dome Installation	26
Figure A-4	Hood Installation	27
Figure A-5	Connection of the Air Distribution Ducts	27
Figure A-6	FAW Logo Embroidery	27

P516811.PDF [Page: 9 of 39]

LIST OF TABLES

Table 3.8-1 Carrying Bag Dimensions 18
Table 4.2-1 FAW III Bill of Materials by Component 20
Table 5-1 FAW III Prototype Assembly Procedure 23

P516811.PDF [Page: 10 of 39]

1. INTRODUCTION

Under a tasking from DCIEM, W7711-8-7479/01-SRV, Order Number 7479-5, Mustang Survival developed a third iteration of the Forced Air Warming (FAW) system concept. The purpose of the development of a new FAW system was to implement the many design modifications that have evolved from the previous two versions as well as additional recommendations from the acquired experience of both the supplier and the technical authority. At the same time, continuous design improvement and value engineering were considered essential to develop a practical and affordable system for future potential FAW users.

With the specific intent of developing a FAW prototype that would lead to a practical field system, Mustang was tasked to design a system compatible with standard Stokes rescue litters that are currently used for SAR operations within Canada. This concept involved the integration of several FAW components to the litter system. In particular, the following components were designed with the intent of permanent installation in the Stokes litter:

- Lower Insulation Blanket (LIB)
- Suspension System
- Body Harnessing System

The additional components of the FAW are intended to be stored separately in a duffel bag and are listed below:

- Arm Insulation Bags
- Leg Insulation Bag
- Torso Dome / Hood
- Upper Air Distribution Manifold
- Lower Air Distribution Manifold
- Electronics System
- Complementary Treatments

This report begins with a general description of the FAW III design and function. Following this overview, a description of each of the components is provided detailing the designs that were chosen to be utilized in the construction of the FAW III final prototype. Additionally, information is provided in this report regarding the construction and assembly of the FAW III prototype. The report is concluded with additional remarks and recommendations for potential improvements to the FAW III prototype for future reference. Finally, supplemental photographs of the FAW prototype are attached in the Appendix.

P516811.PDF [Page: 11 of 39]

2. FAW III GENERAL DESCRIPTION

The FAW III prototype system involves the integration of several components to a SAR Stokes litter for quick assembly and use during field rescue operations. Figure 2-1a below is a picture of the un-modified Stokes litter while Figure 2-1b below is a picture of the final assembly of the FAW prototype.

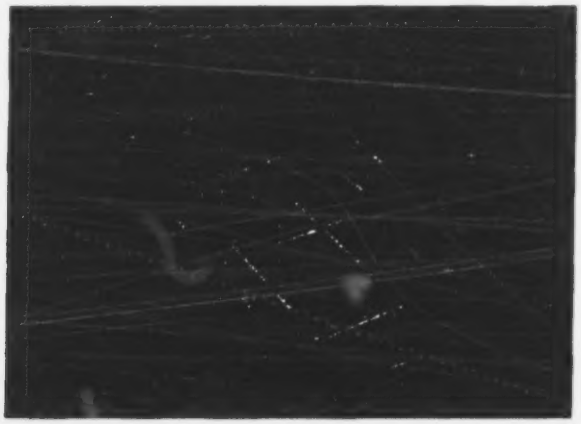

Figure 2-1a Standard Stokes Rescue Litter

Figure 2-1b Final Assembly of the FAW III Prototype

P516811.PDF [Page: 12 of 39]

The FAW system, when installed on a Stokes litter as shown in Figure 2-1b above, provides a chamber around the body of the subject in which heated air may be circulated to actively transfer thermal energy to the body of the subject. In order to prevent excessive power requirement for the heaters, blower and electronics system, the forced air chamber is insulated on all sides as much as is possible (relevant insulation data is provided in subsequent sections). The bottom of the stretcher is insulated against heat loss with a PVC foam blanket (Lower Insulation Blanket, LIB) that mates with the frame of the litter. Similarly, the torso cover and hood components insulate the upper region of the chamber and mate around the perimeter of the LIB and the suspension system. The LIB perimeter folds under the suspension system's frames while the "skirts" of the torso cover and hood tuck behind the back edge of the LIB against the litter shell. To allow circulation of forced air around the back of the subject, the suspension component raises the subject up out of the bottom of the stretcher. The upper body section of the suspension system is a meshed construction of webbing that allows forced air to pass directly to a large portion of the skin area. Beneath the torso of the subject is an air distribution manifold that directs heated air onto the back of the subject. The lower segment of the suspension slightly elevates the legs of the subject in order to promote venal return. Figure 2-2 below shows the LIB, suspension system and the lower air distribution manifold: components that are permanently installed in the Stokes litter.

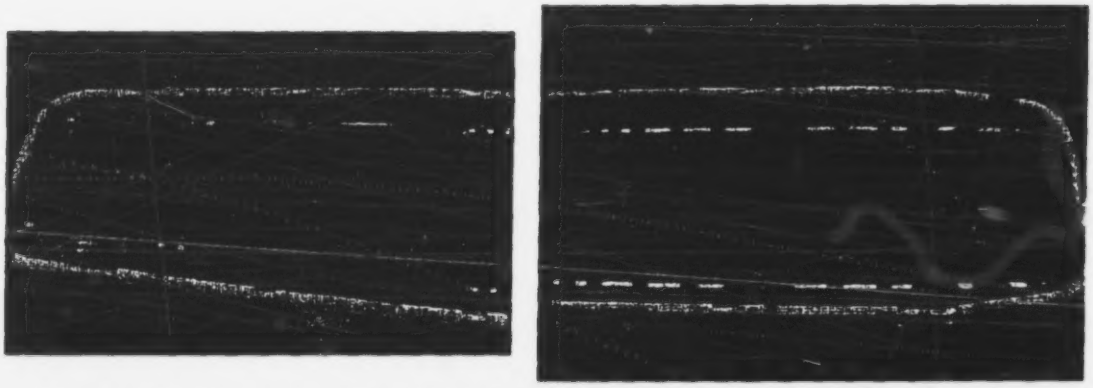

Figure 2-2 Permanently Installed Components in the Stretcher System

Also shown in Figure 2-2 is the subject harness or restraint system. The restraint system is attached to the Stokes litter frame with webbing straps and "slider bar" buckles. The restraint system allows rescue personnel to secure the subject firmly in the litter so that it may be transported without danger of excessive subject movement.

When re-warming a victim of hypothermia it is important to elevate the temperature of the core regions or torso of the body before heating the limbs. This is to prevent a condition known as "after-drop", which is potentially hazardous to the successful

P516811.PDF [Page: 13 of 39]

recovery of the subject. Because of this requirement, passive insulation elements are used to protect the arms and legs from further heat loss and also to prevent venting of the heated air from the forced air chamber. The passive insulation components are shown in Figure 2-1b above. These mate with the torso cover component. The torso cover component is a half cylinder shaped tent structure that is used to support the upper air distribution manifold over the central portion of the subject's body. At the arms interface the torso cover has flaps that strap around the upper arm of the insulation to form a seal. The arms may then be suspended and supported on the torso cover with the slings and by connecting a buckle that is located at the hand end of the arm components. At the foot end interface, it is intended that the bulk of the subject's legs will largely fill the void of the opening and that a seal may be formed between the torso cover and the leg insulation by connecting the foot end flap.

PS16811.PDF [Page: 14 of 39]

3. COMPONENT DESIGNS

The following section details the design of each component of the FAW III system.

3.1. Lower Insulation Blanket (LIB)

In order to create an insulated microenvironment in the Stokes litter, the base of the litter was insulated against heat loss to the external environment. This component was constructed with closed cell PVC foam. Closed cell foam is particularly resistant to the collection of moisture and is capable of providing an appropriate level of thermal insulation. The LIB was designed and constructed so that the rectangular regions between the litter frame and shell are filled with foam blocks. These spaces are clearly seen on Figure 2-1a, the unmodified Stokes litter, shown previously. A "skin" layer of foam connects all of the foam blocks. Furthermore, the skin layer extends from the sides so that it may be folded under the frames of the suspension component. Additionally, a foam block on the topside of the LIB component is located slightly towards the foot end from the envisioned crotch location. This section of foam lays in the transverse direction and serves as a bulkhead to seal the lower section of the heated air chamber. The LIB also has Velcro® loop fastener on the skin side for attachment of the lower air distribution manifold. In order to improve the ability to launder the component, the LIB foam sections were all coated with an orange color solvent based vinyl coating. This coating was spray applied by Russell Products. Figure 3.1-1a below is a sketch of the bottom side of the LIB component while Figure 3.1-1b shows the topside configuration.

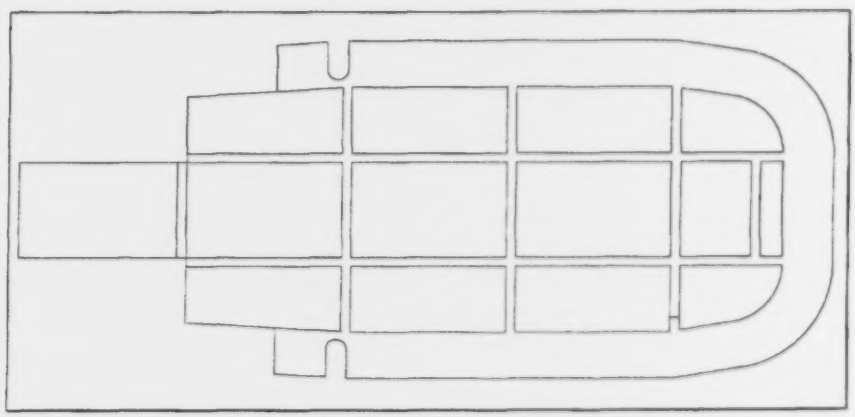

Figure 3.1-1a Sketch – LIB Bottom Side

P516811.PDF [Page: 15 of 39]

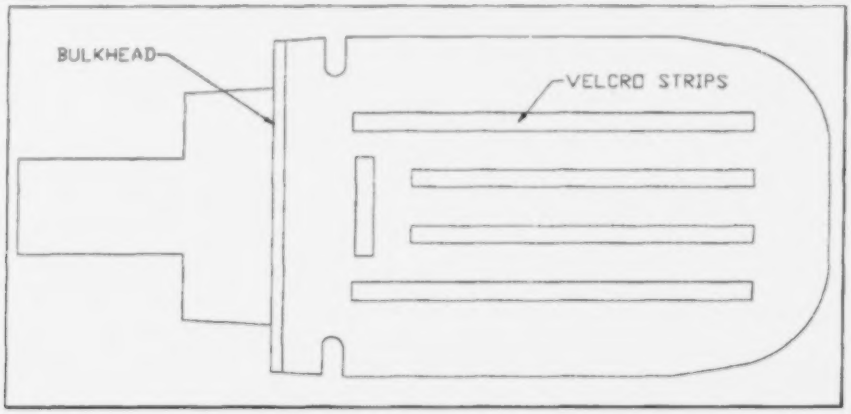

Figure 3.1-1b Sketch – LIB Top Side

The skin layer of the LIB component is constructed from 7-mm closed cell PVC foam whereas the foam blocks are 20-mm thick foam and the bulkhead is 25-mm. The insulation capability was approximated from the results of a simple heat flux test. Heat flux transducers were used to measure the steady state heat transfer rate through the LIB with a test temperature difference of approximately 60-K. The R-Value was determined to be approximately 0.98-m^2K/W (6.3-Clo).

3.2. Suspension System

The suspension system is required in order to allow circulation of heated air to the back of the subject. In addition, the suspension is intended to slightly elevate the legs of the subject relative to the torso in order to promote venal return.

To support the back of the user and at the same time limit the coverage, a box pattern design was developed for 1-in webbing. A configuration was developed that has total coverage by area of 52% leaving 48% of the back of the subject directly exposed to the heated air from the lower air distribution manifold. Many different concepts were tested and evaluated as candidates for the suspension system. However, many of these were either extremely difficult to install and uninstall or had other limitations in terms of integration with other FAW components. As was proposed in the Phase I Report, a suspension design that utilizes aluminum tube side supports was developed. The driving principle was to use connection hardware to fix the suspension supports to the Stokes litter. However, even with the use of ratchet style hardware to attach the suspension it was discovered that the sag inherent in the system could not be sufficiently eliminated. Although required tension forces could physically be achieved, it was at the cost of potentially severe deformation to the Stokes litter frame. As a result of this experience a new design approach was considered appropriate. Using attachment devices capable of providing a single defined tension, the sag of the system could easily be predicted

P516811.PDF [Page: 16 of 39]

over the range of user weights. Based on the predetermined sag dimension, the initial static clearance of the webbing bed was adjusted to provide the appropriate clearance above the air distribution manifold when loaded. Fixed link connectors were used to achieve the defined initial tension in the system. A photograph of these fixed links is shown below in Figure 3.2-1.

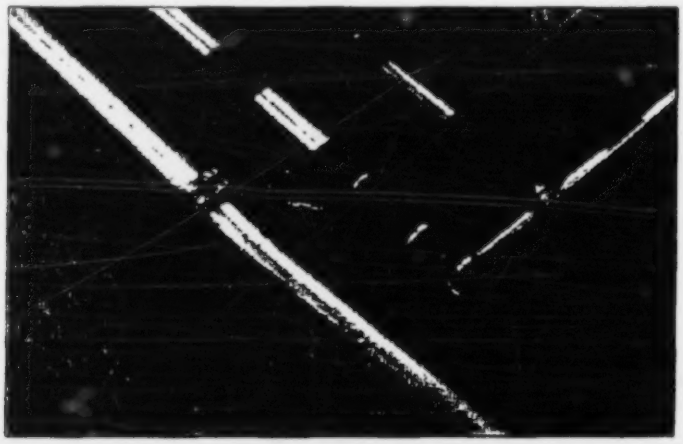

Figure 3.2-1 Fixed Link Attachment System

A canvas support was constructed for the legs of the subject. It is also supported on the sides by aluminum tubing. The leg suspension is connected to the litter with a wire hook on each side at the foot end. The leg support section is connected to the torso/upper body webbing support by "universal joints". High-pressure air hose was used for this joint. Because the leg support is able to rotate about the upper body support it is possible to install the LIB and additional components without removal of the entire suspension assembly. A final feature of the leg support is a pocket on the underside of the canvas section. This sleeve provides a location to store the carrying bag when the FAW is assembled for use. Figure 3.2-2 below is a sketch of the final prototype suspension system.

P516811.PDF [Page: 17 of 39]

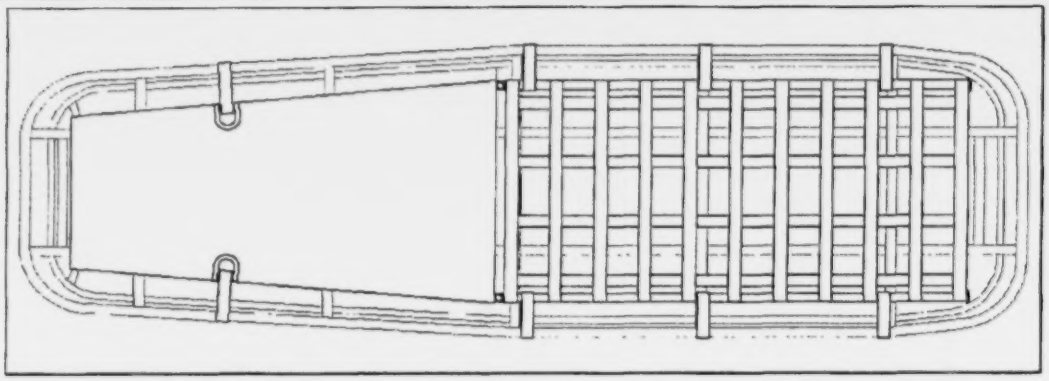

Figure 3.2-2 Final FAW III Prototype Suspension System

3.3. Subject Harness

Because the Stokes litter is used for emergency rescue operations over a variety of complicated terrains, a restraint or harness system was required to prevent undesirable movement of the subject in the litter. The upper body portion of the harness has a strap that connects to the Stokes litter above the shoulder of the subject and near the hip of the subject on each side. The arm of the subject is to be placed through the loop of the harness on each side and the two straps are then buckled together across the chest of the subject and tightened. The legs of the subject are fastened down to the suspension system with two transverse straps that are attached to the Stokes litter. The restraint system is shown installed on subject in Figure 3.3-1 below.

Figure 3.3-1 Subject Restraint System – Upper

P516811.PDF [Page: 18 of 39]

3.4. Passive Insulation for the Limbs

Passive insulation components are required to protect the limbs from continued exposure to the external environment during a rescue operation. In addition, these components are designed to prevent excessive venting of heated air onto the arms and legs. A major requirement of the FAW III development was to reduce the weight and bulk of key components including the arm and leg insulation components. The passive insulation component designs were based on those delivered for the FAW II prototype. Design modifications and improvements are detailed in the following subsections.

3.4.1. Arm Insulation

To protect the arms from exposure to the external environment and the heated air from the forced air chamber, the insulation components are installed over the arm and tightened just below the shoulder with a strap. A double slider zipper is located along the entire length of the component in order to provide emergency access to the hands, wrists and arms without complete removal of the component. An addition to the design is a buckle assembly at the ends of each of the two components. One half of the buckle is attached to each arm insulation component at the hand end and is used to connect the hands together when they are supported on the torso dome. The arm insulation components are shown in Figure 3.4.1-1 below.

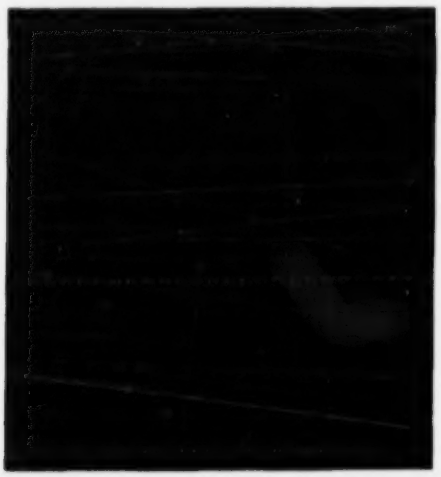

Figure 3.4.1-1 Arm Insulation Components

P516811.PDF [Page: 19 of 39]

The arm insulation components were constructed virtually identical to those that were designed for the FAW II prototype. Major modifications were limited to material changes. The heavy 6-oz. Nomex® shell material was replaced with a non-fire retardant 200-denier urethane coated nylon fabric and the lining fleece was substituted for a lighter weight version. The insulation batting, two layers of 6-oz. Primaloft® Sport, was not changed as per the project Statement of Work requiring that the level of insulation provided be equivalent to that provided under the previous contract. These material changes resulted in a 19% weight reduction of the arm insulation components, slightly less than 24% as predicted in the Phase I report.

3.4.2. Leg Insulation

More significant modifications were made to the leg insulation design. It was deemed that the FAW II component consisted of unnecessary complexities. In particular, the use of two separate zippers to achieve full access to the legs was re-evaluated and the central donning zipper was removed. To facilitate donning of the leg insulation without the central zipper, the foot end zipper was extended along one side to the open end. Additionally, a double slider zipper was substituted into the design. These changes allow the component to be opened completely or only partially for emergency medical access to specific locations on the feet and legs. The final modification to the design was the addition of a Velcro® strip across the upper portion of the component for mating with the torso dome component. Figure 3.4.2-1 below is a picture of the leg insulation component laying on the suspension system in the Stokes litter.

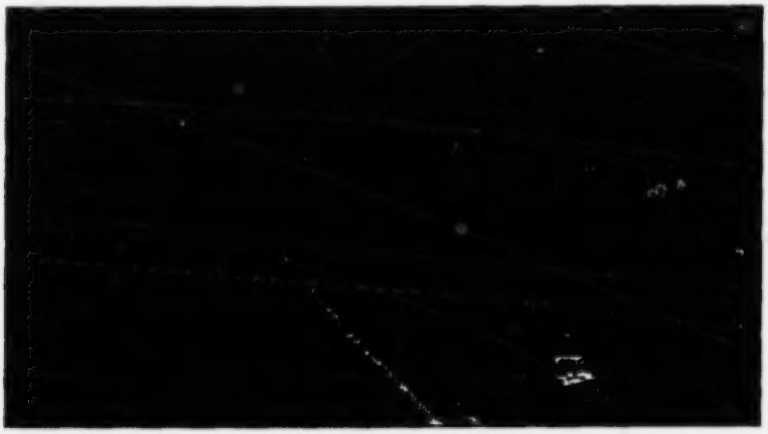

Figure 3.4.2-1 FAW III Leg Insulation Component

P516811.PDF [Page: 20 of 39]

In order to reduce the bulk of the leg insulation component in comparison to the FAW II prototype version, material changes identical to those reported for the arm insulation were implemented. These resulted in a reduction in weight of approximately 20% compared to 25% as predicted in the Phase I report. The reduction in stiffness of the construction materials whilst reducing the weight of the component concurrently reduced the perceived bulk. The replacement materials are also less stiff and facilitate folding and rolling of the component much better than those materials used for previous version.

3.5. Torso Cover

The purpose of the torso cover is to enclose the heated microenvironment around the subject. In addition, the torso cover supports the upper air distribution manifold over the torso of the subject and provides a means of elevating the arms of the subject in order to promote venal return.

During the early stages of the FAW III development, several options existed as potential design solutions for the dome component. These included a fully inflatable construction, a self-inflating mattress (foam structure) style and a simply supported tent structure. Based on experience with the FAW II prototype and other 3D inflatable devices, the inflatable option was discarded. Complications with 3D inflatable construction include extremely cumbersome welding processes and poor weld quality, both of which tend to result in inadequate performance and reliability characteristics in the final product.

An investigation was performed to determine whether or not a construction similar to that used for self-inflating mattresses could be used as a torso cover design. This construction typically involves the lamination of soft open cell PVC foam to polyurethane-coated fabric in a heat press. Using flat panel designs was not practical because multiple inflation points would be required and demonstration proved that the load carrying capability would be quite low. A half cylinder shape seemed most appropriate for this design methodology. However, because of the required cylindrical shape of the torso cover it was not possible to use a heat press for the lamination of a mock-up torso cover. To resolve this construction limitation gluing was proposed as an alternative to heat lamination. Figure 3.5-1 below shows the gluing lay-up for the mockup torso cover.

P516811.PDF [Page: 21 of 39]

Figure 3.5-1 Inflatable Mattress Torso Cover Gluing Lay-up

During evaluation of the mockup cover several inherent limitations of this concept were discovered. The most significant was the difficulty in manufacture. For a planar heat-sealed mattress the practice is to weld the shell around three of the sides before inserting the foam for heat pressing. This was not possible when using gluing to lay-up the component and it was discovered that welding the shell closed after the foam has been laminated is extremely difficult and time consuming. These difficulties result in poor weld quality, leakage and mediocre aesthetics. Additional limitations of this concept that were identified were the inability to properly self-inflate, inadequate structural support characteristics, the use of a very large amount of solvent based gluing chemicals and the inability to integrate many of the other complementary components to the device.

The final design concept was to construct a simply supported tent structure. Several key advantages of this design found immediate favor over the alternative concepts. These were that there is no dependence on the device to be capable of holding air, the ability to use lightweight fabrics and insulation and the use of standard and common manufacturing practices for construction. Furthermore, the tent structure proved capable of meeting other significant performance criteria. The final prototype torso cover is shown in Figure 3.5-2 below.

P516811.PDF [Page: 22 of 39]

Figure 3.5-2 Final Prototype Torso Cover Component

The torso cover component has a half circle structural frame at both the head and foot ends. The frames are constructed from 3/4-in diameter aluminum tubing and have snap clips on the ends that allow the torso cover to connect to the Stokes litter for installation. Carbon fiber tent poles constrain the torso cover to the intended shape. The "shock-cord" elastic that connects that tent poles is attached to the torso cover at one end so that there are no loose parts that may be lost. When the cover is installed on the litter, the cover is mated and sealed to the LIB and suspension by pressing the foam blocks (in the cover "skirt") between the back of the LIB and the litter cover. At the foot end of the device there is a flap with Velcro® fastener that is intended to mate with the leg insulation component to provide a seal. Around the armholes there is a flap that is wrapped around the upper portion of the arm insulation components to obtain a seal. The arms may then be supported on the torso cover with the arm slings on the side of the cover and by connecting the buckle at the hand end of the arm insulation components. As may be seen on the right of Figure 3.5-2, the hood is fully integrated to the torso cover and is in fact part of the same component. On the inside of the torso cover the upper air distribution manifold is connected with Velcro® fastener so that it may be easily installed and removed.

Assembly of the torso cover is simple and can be completed very quickly. When assembled on the final prototype, the torso cover performs admirably. The component is quite capable of supporting the required loads that the arms of the subject will impose and is not subject to dramatic deterioration due to wear and use. Furthermore, the torso cover component folds to a very small size for packing in the carrying bag as can be seen in Figure 3.5-3 below.

P516811.PDF [Page: 23 of 39]

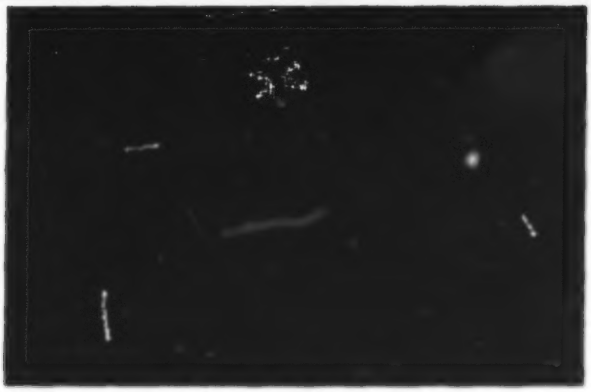

Figure 3.5-3 Torso Cover in the Packed Configuration

The torso cover shell and liner are 200-denier urethane coated nylon fabric while the insulation batting is 1 layer of 6 oz. Primaloft® Sport. The insulation of the torso cover construction was approximated from the results of a simple heat flux test. Heat flux transducers were used to measure the steady state heat transfer rate through the component materials with a test temperature difference of approximately 50-K. The R-Value was determined to be approximately 0.7-m^2K/W (4.5-Clo).

3.6. Hood

Figure 3.6-1 below is a photograph of the hood component in the final assembly configuration.

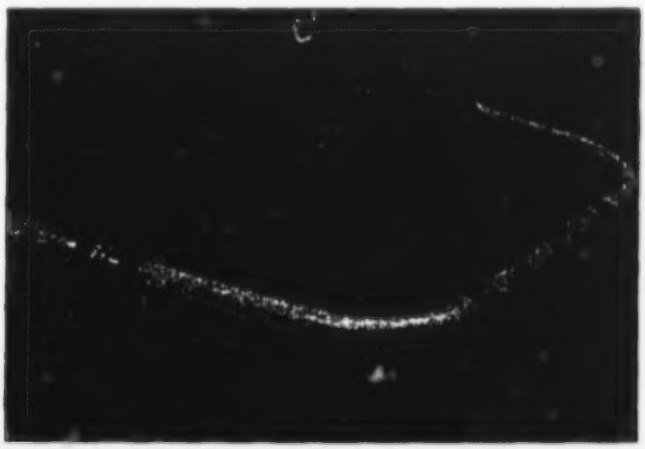

Figure 3.6-1 Hood Component

P516811.PDF [Page: 24 of 39]

The primary requirements of the hood were to mate with the torso dome, suspension and LIB components, to seal the heated microenvironment and partition the face and back of the head so that only the back is exposed to the heated chamber. The hood is permanently attached to the torso dome as indicated and shown in the figure above. The shell and liner are orange 200-denier urethane coated nylon and the insulation batting is one layer of 6-oz Primaloft® Sport Insulation. The head opening is comprised of a fleece fabric with a Neoprene insert to provide a comfortable fit to the face of the subject. The face opening includes a swatch of fleece that is intended to cover the forehead of the subject as is shown in Figure 3.6-1 above. The head hole adjustment is accomplished with a cordloc elastic closure in the perimeter of the head opening.

3.7. Air Distribution

In order to maximize the transfer of thermal energy to the body of the subject, rapid circulation of the heated air within the microenvironment is an important component of the FAW design. As in previous prototypes, the FAW III design incorporates a lower air distribution manifold that is located underneath the back of the subject and an upper air distribution manifold that is attached on the torso dome over the subject. Male and female connectors join the two manifolds by means of flexible corrugated tubing. The designs of the air distribution manifolds are discussed below.

3.7.1. Lower Manifold

The lower air distribution manifold assembles to the LIB below the body of the subject with Velcro® fastener. The inlet of the lower manifold is intended to mate to a connector that in turn mates with the duct from the heater/blower system at the bulkhead of the LIB. Corrugated flexible tubing attaches to the side ducts of the lower manifold in order to divert air to the upper manifold.

Based on process rationales, both air distribution manifolds were designed to be approximately the same. Also, due to the complexity of the welding construction of the previous versions of air distribution systems, a new method of construction was preferable for the FAW III development. Figure 3.7.1-1 below is a sketch of the lower manifold design.

P516811.PDF [Page: 25 of 39]

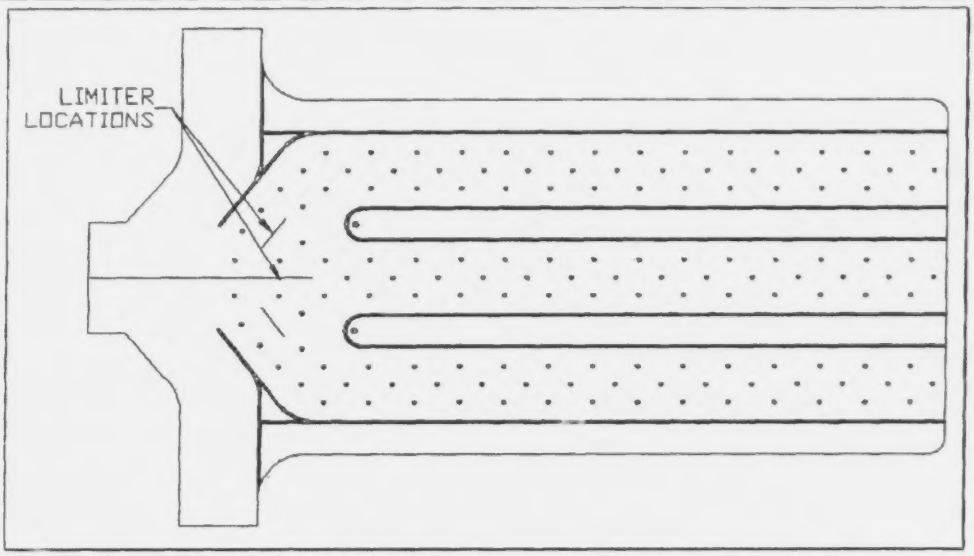

Figure 3.7.1-1 Lower Air Distribution Manifold Sketch

The lower manifold has three branches along the length of the duct. The hole spacing and patterns were designed to be identical to those produced on the previous version of the FAW. However, the holes in the manifold were produced with brass grommets that are intended to act as nozzles in order to promote airflow. The inner diameter of the grommets, the hole diameter, is approximately 0.18-in. There are 142 holes in the manifold for a total flow area of 3.61-in^2.

The central duct shown on the far left in the above figure is the inlet from the heater/blower system and accommodates a 3-in diameter connector. As the air enters the manifold the flow is divided so that air may flow to the upper air distribution manifold from the ducts branching off to the sides. The ducts to the upper manifold are designed to be 25% by area larger than the inlet to the lower manifold to overcome flow restrictions to the upper manifold. Limiters were welded into the manifold inlet section in order to reduce expansion of the manifold when inflated.

Construction of the duct is a hybrid manufacture of RF welding and sewing. In Figure 3.7.1-1 above, the double lines indicate weld locations. Velcro® fastener attachments were sewn to the manifold and the perimeter was sealed with an edge binding that is sewn on.

P516811.PDF [Page: 26 of 39]

3.7.2. Upper Manifold

The upper air distribution manifold connects to the inside of the torso cover component with Velcro® fastener and distributes heated air over the front of the subject's body. As stated in the previous section, air flows into the upper manifold through corrugated ducts from the lower manifold. A sketch of the upper distribution manifold is shown below in Figure 3.7.2-1.

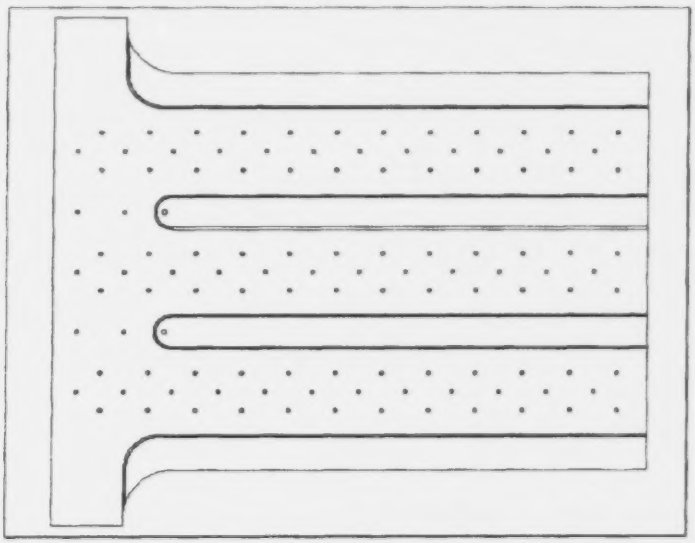

Figure 3.7.2-1 Upper Air Distribution Manifold Sketch

Similar to the lower manifold the upper manifold has three major flow branches. Also like the lower manifold, each of the holes is treated with brass grommets. The upper manifold contains 112 holes providing a total output area of approximately 2.85-in^2. The upper air distribution manifold was constructed in the same manner as described for the lower air distribution manifold.

3.8. Carrying Bag

While some of the components of the FAW III prototype are intended to be permanently installed on the Stokes litter, the remaining components are stored and transported in a carrying bag. The bag is a simple black duffel bag capable of storing the following components:

- Arm Insulation Bags
- Leg Insulation Bag

P516811.PDF [Page: 27 of 39]

- Torso Dome / Hood
- Upper Air Distribution Manifold
- Lower Air Distribution Manifold
- Electronics System
- Complementary Treatments

The approximate dimensions of the carrying bag are provided in the table below.

Table 3.8-1 Carrying Bag Dimensions

Length	27-in
Width	8-in
Height	15-in

3.9. Integration of Complementary Treatments

The Technical Authority visited Mustang Survival during the early phases of the development of the final FAW III prototype. At that time the integration of complementary treatments was discussed with respect to the FAW design. However, insufficient data, concerning the features of the said treatments, was available during this portion of the design phase. Consequently, no specific provisions were included in the design. The Technical Authority and DCIEM, the designers of the complementary treatments, will incorporate these features during the testing and evaluation of the FAW III final prototype.

P516811.PDF [Page: 28 of 39]

4. CONSTRUCTION

The following section provides information regarding the construction of the FAW III prototype unit. The first section provides a brief discussion of the manufacturing processes required to produce the FAW prototype. The second section details the particular materials that were used for construction of the FAW.

4.1. Manufacturing Techniques

One of the significant drawbacks of the FAW II prototype was identified as the inability to economically reproduce the product. Consequently, during the development of the FAW III prototype, the ability to manufacture production units was implemented as a governing evaluation criterion for many of the designs.

In order to reduce the complexity and cost of manufacturing the FAW system, non-standard production processes were either eliminated or reduced dramatically. For example, the FAW II system had components requiring a high degree of complicated 3D RF welding, much of which could only be produced by manual welding. This type of process is extremely time consuming, difficult and associated with a high level of risk in terms of quality (higher probability of arc/burn damage during RF welding). In lieu of this analysis, the components requiring welding, the lower and upper air distribution manifolds, were redesigned so that the welding of production units could be reproduced using one die on an RF welding press.

Another process that was considered desirable to eliminate is gluing. Gluing processes involve the use of costly solvent based chemicals, which many manufacturers are currently moving away from, and often result in poor relative aesthetics. However, gluing was necessary for the construction of the LIB component and hence was not eliminated completely.

Virtually all forms of survival products from clothing, technical garments and suits to parachutes and mountain gear involve the process of sewing. Methods of sewing are well known and applied throughout a variety of industries at an economical value. For this reason sewing was selected and used as the primary construction method for every component possible.

It was not possible to entirely remove all forms of non-standard practice from the design of the FAW III prototype. Several secondary components were designed that do require custom manufacture. These processes or components include the bending of the torso dome support hoops, the inserts used to plug the hoops and the air distribution duct connectors. However, all of these components may be easily ordered and economically produced when required in production quantities.

P516811.PDF [Page: 29 of 39]

4.2. List of Materials

One of the primary motives of the FAW III prototype development was to incorporate value engineering into the design of the device in order to reduce the potential cost of producing a production unit. Accordingly, materials and components on the FAW III prototype were selected in order to ensure that, in as much as possible, they would be available COTS (commercial off the shelf) items. Furthermore, common materials were used across different components of the FAW III prototype to the greatest extent possible. Table 4.2-1 below is a list of each of the materials, by component assembly, on the FAW III final prototype.

Table 4.2-1 FAW III Bill of Materials by Component

Assembly	Part Name	Part No.	Description
Suspension			
	U-Joint	Home Depot	3/8-in ID High Pressure Air Hose (3-in Long)
	Webbing Bed	N0041	1-in Black Nylon Webbing
	Support Tubes	Home Depot	3/4-in OD Al Tubes (37-in Long)
	Canvas Bed	FA-1067-13	500 Denier Cordura
	Support Tubes	Home Depot	3/4-in OD Al Tubes (35-in Long)
	Tube Plugs	4491-K15	Tapered Polyethylene Plug
	Grommets	HD-7580	Brass Dull Black Chemical Grommets
	Screws	Home Depot	Self-Tapping Screws
	Hook Straps	N0041	1-in Black Nylon Webbing
	Upper Hook	3648-T43	Steel Double J-Hook for 1-in Webbing
	Lower Hook	3648-T45	Steel Flat Hook for 1-in Webbing
	Thread - Black	TH-8866-13	CSB 69 Bonded Nylon Thread Black
Body Harness			
	1.5-in Webbing	WE-8501-13	1.5-in Black Nylon Webbing
	1.5-in Buckle	HD-7125-13	TSR150 1.5-in Black Buckle
	Stretcher Attach.	HD-7007	40-mm Slider Bar Buckle
	Harness Hardware	Para-Gear	Sliders, Buckles
	Thread - Black	TH-8866-13	CSB 69 Bonded Nylon Thread Black
Lower Insulation Blanket			
	Foam Skin	FL-3000-10	Airsoft Closed Cell PVC Foam 7-mm
	Foam Blocks	FL-3000-10	Airsoft Closed Cell PVC Foam 20-mm
	Foam Bulkhead	FL-3000-10	Airsoft Closed Cell PVC Foam 25-mm
	Coating	F-830 Orange	Solvent Based Vinyl Spray Coating
	Fastener	VE-9315-13	50-mm Pressure Sensitive Loop Black
Torso Dome			
	Shell	FA-1051-2	1 oz. Orange Tackle
	Insulation	Rain Shed	6 oz. Primaloft® Sport
	Liner	FA-1051-2	1 oz. Orange Tackle
	Foam Inserts	FD-4010	Open Cell Foam - Mattress Sheet
	Tube Supports	Home Depot	3/4-in OD Al Tubes (Half Circle)

P516811.PDF [Page: 30 of 39]

	Tube Plugs	Skyward	Delrin Plug Inserts
	Spring Clips	1723-A64	Vinyl Coated Steel Spring Clip + Screws
	Tent Poles	3-Vets	Fiber-Glass Tent Poles (Cut to Length)
	Shock Cord	EL-1011-13	2.3-mm Drawstring Elastic
	Tent Pole Pocket	WE-8501-13	1.5-in Black Nylon Webbing
	Flap Tab	TA1027-13	1-in Gross Grain Ribbon Tape - Black
	1.5-in Webbing	WE-8501-13	1.5-in Black Nylon Webbing
	Buckle	HD-7125-13	TSR-150 Black Buckle
	38-mm Fastener	VE-9200-13	38-mm Black Hook Fastener
	38-mm Fastener	VE-9210-13	38-mm Black Loop Fastener
	25-mm Fastener	VE-9100-13	25-mm Black Hook Fastener
	25-mm Fastener	VE-9110-13	25-mm Black Loop Fastener
	19-mm Fastener	VE-9000-13	19-mm Black Hook Fastener
	Thread - Orange	TH-8866-2	CSB 69 Bonded Nylon Thread Orange
	Thread - Black	TH-8866-13	CSB 69 Bonded Nylon Thread Black
	DCIEM FAW Logo	Custom	Embroidery
	Mustang Logo	LA-4525-10	Mustang Survival Logo, White/Navy/Red
Hood			
	Shell	FA-1051-2	1 oz. Orange Tackle
	Insulation	Rain Shed	6 oz. Primaloft® Sport
	Liner	FA-1051-2	1 oz. Orange Tackle
	Elastic	EL-1000-13	1-in Black Elastic
	Face Sleeve	FA-1086-13	Polyester Black Fleece
	Face Padding	FD-2337-13	1.5-mm Smooth Skin Neoprene
	Drawstring	EL-1011-13	2.3-mm Drawstring Elastic
	Cordloc	HD-7029-13	Cordloc Black, Posi-Grip
	38-mm Fastener	VE-9200-13	38-mm Black Hook Fastener
	19-mm Fastener	VE-9000-13	19-mm Black Hook Fastener
	25-mm Fastener	VE-9110-13	25-mm Black Loop Fastener
	Thread - Orange	TH-8866-2	CSB 69 Bonded Nylon Thread Orange
	Thread - Black	TH-8866-13	CSB 69 Bonded Nylon Thread Black
Arm Insulation			
	Shell	FA-1051-2	1 oz. Orange Tackle
	Insulation	Rain Shed	6 oz. Primaloft® Sport - 2 Layers
	Liner	FA-1086-13	Polyester Black Fleece
	Zipper	ZI-3005-13	VFMC 106 #580 - 31-in Black
	1.5-in Webbing	WE-8501-13	1.5-in Black Nylon Webbing
	1-in Webbing	WE-8500-13	1-in Black Nylon Webbing
	1-in Buckle	HD-7100-13	TSR100 1-in Black Buckle
	Loop Slider	HD-7208-13	1.5-in Black Loop LH38E
	Fastener	VE-9200-13	38-mm Black Hook Fastener
	Fastener	VE-9210-13	38-mm Black Loop Fastener
	Thread - Orange	TH-8866-2	CSB 69 Bonded Nylon Thread Orange
	Thread - Black	TH-8866-13	CSB 69 Bonded Nylon Thread Black

P516811.PDF [Page: 31 of 39]

Leg Insulation			
	Shell	FA-1051-2	1 oz. Orange Tackle
	Insulation	Rain Shed	6 oz. Primaloft Sport® - 2 Layers
	Liner	FA-1086-13	Polyester Black Fleece
	Zipper	34000-580-72	VFMC 106 #580 - 72-in Black
	1.5-in Webbing	WE-8501-13	1.5-in Black Nylon Webbing
	1.5-in Buckle	HD-7125-13	TSR150 1.5-in Black Buckle
	Fastener	VE-9200-13	38-mm Black Hook Fastener
	Fastener	VE-9210-13	38-mm Black Loop Fastener
	Thread - Orange	TH-8866-2	CSB 69 Bonded Nylon Thread Orange
	Thread - Black	TH-8866-13	CSB 69 Bonded Nylon Thread Black
Air Distribution Ducts			
	Fabric	Misc.	200 Denier, PU Coated, Weldable, Black
	Edge Binding	TA-1025-13	1.5-in Black Tackle Bias Tape
	Grommets	HD-7580	Brass Dull Black Chemical Grommets
	Thread - Black	TH-8866-13	CSB 69 Bonded Nylon Thread Black
Air Distribution Connectors			
	Tubing		Flexible Corrugated Tubing
	Connectors	Skyward	Custom Design – Male and Female Connectors

P516811.PDF [Page: 32 of 39]

5. ASSEMBLY INSTRUCTIONS

The prototype system was demonstrated by means of a video as per the requirements of the development contract. The video documentation serves as the authoritative reference with respect to the assembly of the FAW system to the Stokes litter. However, Table 5-1 below is a list of the step-wise procedure required to assembly the FAW III prototype.

Table 5-1 FAW III Prototype Assembly Procedure

Step	Component	Instruction
1	Harness/Restraint	Install the Subject Restraint System Components
2	LIB	Press the LIB into the Stokes Litter.
3	Lower Air Manifold	Install the Lower Air Distribution Manifold on the LIB (Velcro® Fastener)
4	Electronics	Insert the Electronics Box in the Litter and Connect the Lower Air Distribution Manifold
5	Suspension	Install the Suspension System Connecting the Wire Hooks to the Upper Bar of the Litter and the Flat Hooks to the Lower Bar
6	LIB	Fold the LIB Flap Under the Suspension Support Tubes and Connect the Velcro®
7	Upper Air Manifold	Install the Upper Air Distribution Manifold in the Torso Cover
8	Leg Insulation	Open Leg Insulation and Lay on the Canvas Suspension
9	Subject	Lay Subject on the Suspension System
10	Leg Insulation	Close and Tighten the Leg Insulation
11	Harness/Restraint	Tighten the Subject Restraint System
12	Arm Insulation	Install and Tighten the Arm Insulation on the Subject
13	Torso Cover & Hood	Erect the Torso Cover by Connecting the Tent Poles, Snap the Torso Cover on the Litter Over the Subject and Fix the Arm Flap Around the Arm Insulation
14	Arm Insulation	Place Arms Through the Torso Cover Slings and Connect the Buckle at the Arm Insulation Ends
15	Hood	Pull the Hood Over the Head of the Subject, Adjust the Face Closure and Tuck the Skirt Around the LIB Perimeter
16	Torso Cover	Tuck the Skirt Around the LIB Perimeter
17	Air Distribution Connectors	Connect the Lower and Upper Air Distribution Connectors
18	Torso Cover	Seal the Leg End of the Torso Cover
19	Controls	Activate Rewarming System
20	Carrying Bag	Store Carrying Bag in the Sleeve Pocket on the Leg Canvas Underside

P516811.PDF [Page: 33 of 39]

6. CONCLUSION

The primary goals for the development of the FAW III prototype system were to eradicate the deficiencies that were discovered with previous versions, design a system that would be feasible to manufacture at a reasonable cost and to reduce the overall weight and bulk of the system. These requirements were intended to be met without a considerable sacrifice in the level of performance of the device.

Many of the deficiencies identified for previous versions of the FAW system have been overcome. In particular, the current design is inherently simple to assemble to the rescue litter quickly and reliably. In addition, the FAW III prototype sufficiently overcomes structural and degradation problems that have been experienced in the past. The FAW III system was designed with the specific intent of being durable when exposed to the most extreme conditions.

As noted in previous sections in this report, particular care was considered during the design and development phase with respect to the ability to have repeatable manufacturing of the system. Common production practice and COTS materials were utilized to minimize costs to order and costs to build.

The perceived bulk of the FAW system has been notably reduced during the development of the FAW III prototype. Of particular significance is that drastic reduction in bulk that was achieved from material substitutions. This includes the removal of the requirement that the device be fire retardant. This allowed the elimination of the heavy and bulky Nomex® fabric as well as the reduction of the use of double-polyurethane-coated weldable fabrics in the torso dome and air distribution ducts. Additional improvements to the FAW include designs that are intended to provide a seamless integration of components. The final total weight of the FAW III prototype, as delivered to DCIEM without the electronics system, was measured as approximately 52-lbs (Phase I Interim Report prediction: 48-lbs). This result is a significant improvement over the FAW II prototype, which when delivered had a total weight of approximately 105-lbs.

Testing to be performed by DCIEM will determine the relative performance of the FAW III prototype system. Known deficiencies and some recommendations are noted in the following section of this report.

P516811.PDF [Page: 34 of 39]

7. RECOMMENDATIONS

This section provides a point form list of recommendations that may require implementation to enhance the performance of the FAW III system to the appropriate level. Known deficiencies that exist within the system, as it was provided to the Technical Authority, are also noted.

- Flexible high-pressure air hose was used as a universal joint between the upper and lower suspension. A traditional component should be substituted to perform this function.
- The center of gravity (COG) of the loaded system may be too high to allow safe transport by certain methods. The static position of the suspension may need to be lowered.
- The inlet and flow division section of the lower air distribution manifold may exhibit an unacceptable amount of expansion when inflated during operation. Modification to the limiter design may be required to rectify this problem.
- Airflow may be restricted in the distribution manifolds. If this is identified as a problem, Mustang recommends the addition of spacer fabric in regions suspected of "kinking".
- It may not be possible to achieve an adequate seal against air loss at the foot end of the torso cover. A modification to the flap is recommended to improve the mating of the components.
- Modification may be required to the skirt of the torso cover and hood components if an adequate seal cannot be obtained.

P516811.PDF [Page: 35 of 39]

APPENDIX: SUPPLEMENTAL PHOTOGRAPHS

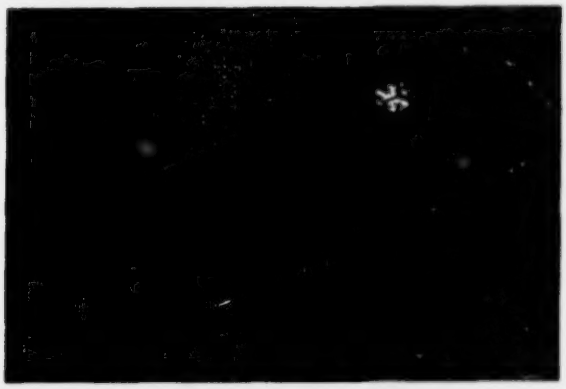

Figure A-1 FAW Final Assembly – Top View

Figure A-2 Installation of the Subject

Figure A-3 Dome Installation

P516811.PDF [Page: 36 of 39]

Figure A-4 Hood Installation

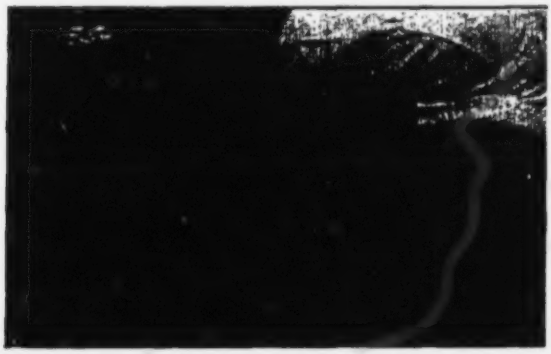

Figure A-5 Connection of the Air Distribution Ducts

Figure A-6 FAW Logo Embroidery

P516811.PDF [Page: 37 of 39]

DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY	2 SECURITY CLASSIFICATION
Mustang Survival (Richmond, BC, V6V 1Y6)	UNCLASSIFIED Unlimited distribution -
1b PUBLISHING AGENCY	
DCIEM	

3. TITLE

(U) Forced air warming system: Prototype III final report

4. AUTHORS

Jason Leggatt

5. DATE OF PUBLICATION	6 NO. OF PAGES
October 15 , 2001	27

7. DESCRIPTIVE NOTES

8 SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY
Sponsoring Agency
Monitoring Agency:
Contracting Agency :
Tasking Agency: DCIEM

9. ORIGINATORS DOCUMENT NO	10. CONTRACT GRANT AND/OR PROJECT NO	11. OTHER DOCUMENT NOS
Contract Report CR 2001-008	W7711-8-7479/01-SRV	

12. DOCUMENT RELEASABILITY

Unlimited distribution

13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

P516811.PDF [Page: 38 of 39]

14. ABSTRACT

(U) This report details the design and development of a Forced Air Warming (FAW) system for the Defence and Civil Institute of Environmental Medicine (DCIEM). Mustang Survival Corporation partnered with DCIEM in the development of two previous versions of FAW systems. Thus the present version has been appropriately named the FAW III.

Previous versions of the FAW concept successfully demonstrated that such a system, if deployed in the field, would have the capability of providing a 30% increase in re-warming efficiency compared to warming bags currently used during Search and Rescue (SAR) operations. Current field treatment systems for hypothermia use a combination of active and passive warming. The primary mode of heat transfer in these systems is conduction; the bag is actively heated. Passive insulation is used to mitigate against heat loss to the environment. The premise of the FAW system is to utilize a higher form of heat transfer, convection, for immediate treatment of subjects suffering from hypothermia. This is achieved by creating a heated microenvironment around the subject's body by blowing heated air through air distribution manifolds. However, several limitations for the field use of the previous two prototypes were identified and a third iteration of the FAW was initiated. The purpose of the present FAW is to lay the groundwork for a final design that will ultimately lead to a commercially available system.

The FAW III system serves the following two primary functions in re-warming a subject.

- Passive insulation and passive re-warming of the subject's legs and arms.
- Active forced air warming of the subject's torso and back of the head by means of a heated microenvironment.

The current version of the FAW was designed to be integrated with a Stokes rescue litter. A vinyl coated foam blanket is used to insulate the stretcher bottom and was designed to mate with the litter frame and the body supporting suspension system. A custom suspension system supports the body out of the bottom of the litter. The upper body portion was constructed from nylon webbing in a box-shaped pattern so that the back of the subject will be largely exposed, approximately 50%. The lower body and legs are supported on a solid canvas bed that rests on top of the electronics box component. A body harness design is also incorporated into the litter system. These components are intended to be permanently installed but can be easily removed for laundering. The lower air distribution manifold connects to the foam insulation blanket and may either be left in the litter or stored separately.

Additional components of the FAW system are stored in a carrying bag. Passive insulation components for the arms and the legs are installed on the subject and tightened to dam the passage of air from the heated chamber to the extremities. Finally, a dome is installed over the torso section of the body and mates with the suspension and foam insulation components. This dome supports the upper air distribution manifold over the torso of the subject's body. A hood cover, integrated into the torso cover design, mates around the subject's head and the foam insulation blanket to seal the heated microenvironment.

The electronic components of the system, including the controls system, heaters, blower and displays are to be supplied and installed by DCIEM. Accommodation for integration of the electronics to the FAW was considered throughout the design stage. Complementary treatments and additional features will be integrated into the FAW design during and following testing and evaluation of the prototype at DCIEM.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) field rewarming; hypothermia; cold; treatment